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## ABSTRACT

Presented are the teacher's guide and student manual for one of a series of self-instructional, computer-based learning modules for an introductory, undergraduate chemistry course. The student manual for this solution stoichiometry unit includes objectives, prerequisites, pretest, discussion, and 20 problem sets. Included in the teacher's guide are implementation instructions, software, answers to problems, extensions, sample run, program listing in BASIC, and 10 unit tests. (BT)

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SOLUTIONS  
UNIT 4. SOLUTION STOICHIOMETRY

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A COMPUTER-ENRICHED MODULE  
FOR INTRODUCTORY CHEMISTRY



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## OBJECTIVES

When you are finished with this unit you will be able to

1. work solution stoichiometry problems involving molarity, solution volume and moles.
2. work solution stoichiometry problems in terms of normality and equivalents for both acid-base and redox reactions.

## PREREQUISITES

Before beginning this unit you should be familiar with general stoichiometry, concentration and dilution, and know the definitions of the following terms: acid, base, oxidizing agent, reducing agent. If you plan to do the equivalents part of this unit, you should be able to balance redox equations and know the definitions of Brönsted acids and bases.

## PRE-TEST

1. When 200.0 ml of 0.400 molar NaCl solution are diluted to a final volume of 500.0 ml, what is the final molar concentration of NaCl?
2. What weight of Fe (55.85 g/mole) can be produced from 3.2 g of  $\text{Fe}_2\text{O}_3$  (160 g/mole)?



Answers to pre-test:

1. 0.160 molar
2. 2.23 g

## INTRODUCTION

In a previous unit you learned how to obtain the number of moles of a reactant used up (or product formed) given the number of moles of another reactant used up (or product formed). A typical problem might be:

Example 1. How many grams of solid  $\text{Ag}_2\text{SO}_4$  (312 g/mole) can be precipitated from 1.70 g of  $\text{AgNO}_3$  (169.9 g/mole) dissolved in aqueous solution?  $\text{H}_2\text{SO}_4$  is present in excess.



$$\underbrace{\left[ \underbrace{(1.70 \text{ g AgNO}_3) \left( \frac{1 \text{ mole AgNO}_3}{169.9 \text{ g AgNO}_3} \right)}_{\text{moles AgNO}_3} \right] \left( \frac{1 \text{ mole Ag}_2\text{SO}_4}{2 \text{ moles AgNO}_3} \right) \left( \frac{312 \text{ g Ag}_2\text{SO}_4}{1 \text{ mole Ag}_2\text{SO}_4} \right)}_{\text{moles Ag}_2\text{SO}_4} = 1.56 \text{ g Ag}_2\text{SO}_4$$

conversion factor

One converts from moles of one reagent (here  $\text{AgNO}_3$ ) to moles of another reagent (here  $\text{Ag}_2\text{SO}_4$ ) by multiplying by a conversion factor, which is the ratio of coefficients in the balanced chemical equation. The same procedure is followed in solution stoichiometry problems, except that the number of moles is commonly obtained from molarity-volume data instead of weight-formula weight data. Contrast the above example with the next one.

Example 2. What weight of solid  $\text{Ag}_2\text{SO}_4$  (312 g/mole) can be precipitated from 100. ml of a 0.100 molar  $\text{AgNO}_3$  solution?  $\text{H}_2\text{SO}_4$  is in excess.

$$\underbrace{\left( \frac{0.100 \text{ moles AgNO}_3}{1 \text{ liter AgNO}_3 \text{ soln}} \right) (100 \text{ ml AgNO}_3 \text{ soln})}_{\text{moles AgNO}_3} \underbrace{\left( \frac{1 \text{ liter AgNO}_3 \text{ soln}}{1000 \text{ ml AgNO}_3 \text{ soln}} \right) \left( \frac{1 \text{ mole Ag}_2\text{SO}_4}{2 \text{ moles AgNO}_3} \right)}_{\text{conversion factor}} \cdot \left( \frac{312 \text{ g Ag}_2\text{SO}_4}{1 \text{ mole Ag}_2\text{SO}_4} \right) = 1.56 \text{ g Ag}_2\text{SO}_4$$

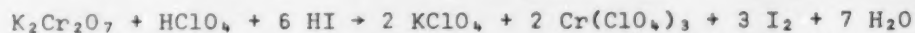
The two problems are the same, except that the number of moles of  $\text{AgNO}_3$  is found from weight-formula weight data in Example 1, and from molarity-volume data in Example 2. Solution stoichiometry problems are mainly of the second type.

## DISCUSSION

### THE GENERAL METHOD

Problems involving amounts of substances reacting in solution can be solved by using the same dimensional analysis which we used in solving simple stoichiometry problems.

Example 3. What volume of 0.100 molar  $\text{K}_2\text{Cr}_2\text{O}_7$  (an oxidizing agent) is needed to exactly react with 300.0 ml of 0.200 molar HI (a reducing agent)?



Moles reducing agent:

$$(300.0 \text{ ml HI soln}) \left( \frac{0.200 \text{ moles HI}}{1 \text{ liter HI soln}} \right) \left( \frac{1 \text{ liter HI soln}}{1000 \text{ ml HI soln}} \right) = 6.00 \times 10^{-2} \text{ moles HI}$$

Moles oxidizing agent:

$$(6.00 \times 10^{-2} \text{ moles HI}) \left( \frac{1 \text{ mole K}_2\text{Cr}_2\text{O}_7}{6 \text{ moles HI}} \right) = 1.00 \times 10^{-2} \text{ moles K}_2\text{Cr}_2\text{O}_7$$

Volume oxidizing agent:

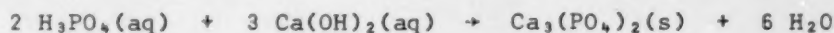
$$(1.00 \times 10^{-2} \text{ moles K}_2\text{Cr}_2\text{O}_7) \left( \frac{1 \text{ liter K}_2\text{Cr}_2\text{O}_7 \text{ soln}}{0.100 \text{ moles K}_2\text{Cr}_2\text{O}_7} \right) \left( \frac{1000 \text{ ml K}_2\text{Cr}_2\text{O}_7 \text{ soln}}{1 \text{ liter K}_2\text{Cr}_2\text{O}_7 \text{ soln}} \right) = 200 \text{ ml K}_2\text{Cr}_2\text{O}_7 \text{ solution.}$$

Of course we can get the same result in one big step:

$$\begin{aligned}
 & (300.0 \text{ ml HI}) \left( \frac{0.200 \text{ moles HI}}{1 \text{ liter HI}} \right) \left( \frac{1 \text{ liter HI}}{1000 \text{ ml HI}} \right) \left( \frac{1 \text{ mole K}_2\text{Cr}_2\text{O}_7}{6 \text{ moles HI}} \right) \cdot \\
 & \cdot \left( \frac{1 \text{ liter K}_2\text{Cr}_2\text{O}_7 \text{ soln}}{0.1 \text{ mole K}_2\text{Cr}_2\text{O}_7} \right) \left( \frac{1000 \text{ ml K}_2\text{Cr}_2\text{O}_7 \text{ soln}}{1 \text{ liter K}_2\text{Cr}_2\text{O}_7 \text{ soln}} \right) = \\
 & = \frac{300.0 \times 0.200}{6 \times 0.1} \text{ ml K}_2\text{Cr}_2\text{O}_7 \text{ soln} .
 \end{aligned}$$

The most common student error in this type of problem results from failure to write down the units completely, e.g., ml K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> solution, not just ml or ml K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> or ml solution. Although you can sometimes get the correct answer by being sloppy with units, at other times the results are spectacularly disastrous.

Example 4. If 133 ml of a certain H<sub>3</sub>PO<sub>4</sub> solution is needed to exactly react with 400.0 ml of 0.100 molar Ca(OH)<sub>2</sub> solution, what is the molarity of the H<sub>3</sub>PO<sub>4</sub>?



Moles base:

$$\begin{aligned}
 & (400.0 \text{ ml Ca(OH)}_2 \text{ soln}) \left( \frac{0.100 \text{ moles Ca(OH)}_2}{1 \text{ liter Ca(OH)}_2 \text{ soln}} \right) \left( \frac{1 \text{ liter Ca(OH)}_2 \text{ soln}}{1000 \text{ ml Ca(OH)}_2 \text{ soln}} \right) = \\
 & = 4.00 \times 10^{-2} \text{ moles Ca(OH)}_2
 \end{aligned}$$

Moles acid:

$$(4.00 \times 10^{-2} \text{ moles Ca(OH)}_2) \left( \frac{2 \text{ moles H}_3\text{PO}_4}{3 \text{ moles Ca(OH)}_2} \right) = 2.67 \times 10^{-2} \text{ moles H}_3\text{PO}_4$$

Molarity acid:

$$\begin{aligned}
 & (2.67 \times 10^{-2} \text{ moles H}_3\text{PO}_4) \left( \frac{1}{133 \text{ ml H}_3\text{PO}_4 \text{ soln}} \right) \left( \frac{1000 \text{ ml H}_3\text{PO}_4 \text{ soln}}{1 \text{ liter H}_3\text{PO}_4 \text{ soln}} \right) = \\
 & = 0.200 \frac{\text{moles H}_3\text{PO}_4}{\text{liter H}_3\text{PO}_4 \text{ soln}} = 0.200 \text{ M}
 \end{aligned}$$

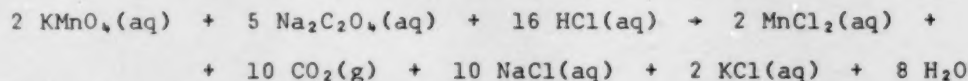
In practice you will want to do the problem in one step:

$$\begin{aligned}
 & \left( \frac{400.0 \text{ ml Ca(OH)}_2 \text{ soln}}{133 \text{ ml H}_3\text{PO}_4 \text{ soln}} \right) \left( \frac{0.100 \text{ mole Ca(OH)}_2}{1 \text{ liter Ca(OH)}_2 \text{ soln}} \right) \left( \frac{1000 \text{ ml H}_3\text{PO}_4 \text{ soln}}{1 \text{ liter H}_3\text{PO}_4 \text{ soln}} \right) \cdot \\
 & \cdot \left( \frac{2 \text{ moles H}_3\text{PO}_4}{3 \text{ moles Ca(OH)}_2} \right) \left( \frac{1000 \text{ ml Ca(OH)}_2 \text{ soln}}{1 \text{ liter Ca(OH)}_2 \text{ soln}} \right)
 \end{aligned}$$

Problem 5. A 1.00 ml sample of battery acid (H<sub>2</sub>SO<sub>4</sub>) requires 12.37 ml of 1.12 molar NaOH to exactly react with it. What is the molarity of the H<sub>2</sub>SO<sub>4</sub>?



Problem 6. To 30.15 ml of 0.100 molar Na<sub>2</sub>C<sub>2</sub>O<sub>4</sub> (a colorless solution) was added dropwise a solution of KMnO<sub>4</sub> (a deep purple solution).



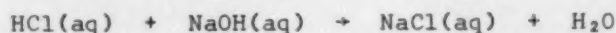
All the products of this reaction are colorless. After 16.44 ml of the KMnO<sub>4</sub> solution had been added, the solution took on a pinkish color, in-

dicating that the reaction was complete and additional  $\text{KMnO}_4$  would not react. What is the molarity of the original  $\text{KMnO}_4$  solution?

#### COMPUTER ASSIGNMENT

Go to the computer and run the program ENDPT. This is a game in which you add volumes of  $\text{NaOH}$  solution (of known concentration) to a sample of  $\text{HCl}$  solution of known volume but unknown concentration. When more  $\text{NaOH}$  has been added than can react with the  $\text{HCl}$  present, the solution changes color because of an indicator chemical that has been added. This process of adding known volumes of a reagent of known concentration to a known volume of another reagent of unknown concentration is called "titration". Problems 5 and 6 are really titrations.

In this program,  $\text{HCl}$  is being titrated with  $\text{NaOH}$ .



Thus, the conversion factor is  $\left( \frac{1 \text{ mole HCl}}{1 \text{ mole NaOH}} \right)$  so that in this case, moles acid does equal moles base.

#### THE EQUIVALENCE METHOD (ACIDS AND BASES)

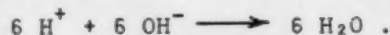
There is another procedure used to work solution stoichiometry problems which does not require the unit conversion factor between reagents, i.e. does not require a balanced equation. This approach is called the equivalence method. Consider Example 4 given previously:



It is obvious that the moles of acid ( $\text{H}_3\text{PO}_4$ ) do not equal the moles of base ( $\text{Ca(OH)}_2$ ). However, if all the reagents are considered to be completely ionized in solution, then



and if one disregards the spectator ions (bottom line) which are the same on both sides of the equation, then



In this equation the moles of  $\text{H}^+$  (not moles of acid) are indeed equal to the moles of  $\text{OH}^-$  (not moles of base).

In order to make use of this equality, chemists have defined a new term -- the equivalent. The number of equivalents is always the number of moles times an integer. For acids, this integer is the number of ionizable hydrogens, i.e. 1 for  $\text{HCl}$ , 2 for  $\text{H}_2\text{SO}_4$ , 3 for  $\text{H}_3\text{PO}_4$ , etc. For bases it is the number of  $\text{H}^+$ 's which a formula unit can accept, i.e. 1 for  $\text{NaOH}$  (the  $\text{OH}^-$  can accept a  $\text{H}^+$ ), 2 for  $\text{Ba(OH)}_2$ , 2 for  $\text{Na}_2\text{CO}_3$  ( $\text{CO}_3^{2-}$  can accept 2  $\text{H}^+$ 's to become  $\text{H}_2\text{CO}_3$ ), etc. Sometimes there are surprises (only one of the H's in acetic acid,  $\text{H}_4\text{C}_2\text{O}_2$ , is ionizable) but you'll be told about them before you have to use them.

Example 7. How many equivalents are there in 9.8 g of ortho phosphoric acid (98 g/mole) when it reacts to form  $\text{Na}_3\text{PO}_4$ ?

$$\underbrace{(9.8 \text{ g H}_3\text{PO}_4) \left( \frac{1 \text{ mole H}_3\text{PO}_4}{98 \text{ g H}_3\text{PO}_4} \right)}_{\text{moles H}_3\text{PO}_4} \underbrace{\left( \frac{3 \text{ equiv H}_3\text{PO}_4}{1 \text{ mole H}_3\text{PO}_4} \right)}_{\text{"integer"}} = 0.30 \text{ equiv H}_3\text{PO}_4$$

Example 8. How many equivalents are there in 200.0 ml of 0.500 molar  $\text{H}_3\text{PO}_4$  solution, when it reacts to form  $\text{Na}_3\text{PO}_4$ ?

$$\underbrace{(200 \text{ ml H}_3\text{PO}_4 \text{ soln}) \left( \frac{0.500 \text{ moles H}_3\text{PO}_4}{\text{liter H}_3\text{PO}_4 \text{ soln}} \right) \left( \frac{1 \text{ liter H}_3\text{PO}_4 \text{ soln}}{1000 \text{ ml H}_3\text{PO}_4 \text{ soln}} \right)}_{\text{moles H}_3\text{PO}_4} \cdot \underbrace{\left( \frac{3 \text{ equiv H}_3\text{PO}_4}{1 \text{ mole H}_3\text{PO}_4} \right)}_{\text{"integer"}} = 0.300 \text{ equiv H}_3\text{PO}_4$$

The inconvenience of introducing this extra step is more than compensated for by the elimination of the step converting the amount of the substance into the amount of the other substance with which it reacts. The 0.3 equivalents of  $\text{H}_3\text{PO}_4$  will react with 0.3 equivalents of any base, and you don't have to have the balanced equation in front of you in order to work the problem.

Example 9. What volume of 0.10 molar  $\text{H}_2\text{SO}_4$  will completely react with 30.0 ml of 0.40 molar NaOH?

Equivalents base:

$$(30.0 \text{ ml NaOH soln}) \left( \frac{0.40 \text{ moles NaOH}}{\text{liter NaOH soln}} \right) \left( \frac{1 \text{ liter NaOH soln}}{1000 \text{ ml NaOH soln}} \right) \left( \frac{1 \text{ equiv NaOH}}{1 \text{ mole NaOH}} \right) = 1.2 \times 10^{-2} \text{ equiv NaOH}$$

Equivalents acid:

$$(1.2 \times 10^{-2} \text{ equiv NaOH}) \left( \frac{1 \text{ equiv H}_2\text{SO}_4}{1 \text{ equiv NaOH}} \right) = 1.2 \times 10^{-2} \text{ equiv H}_2\text{SO}_4$$

Volume acid:

$$(1.2 \times 10^{-2} \text{ equiv H}_2\text{SO}_4) \left( \frac{1 \text{ mole H}_2\text{SO}_4}{2 \text{ equiv H}_2\text{SO}_4} \right) \left( \frac{\text{liter H}_2\text{SO}_4 \text{ soln}}{0.10 \text{ moles H}_2\text{SO}_4} \right) \cdot \left( \frac{1000 \text{ ml H}_2\text{SO}_4 \text{ soln}}{1 \text{ liter H}_2\text{SO}_4 \text{ soln}} \right) = 6.0 \times 10^1 \text{ ml H}_2\text{SO}_4 \text{ soln}$$

Note that the (equiv NaOH) and (equiv  $\text{H}_2\text{SO}_4$ ) terms cancel because of the definition of the term equivalent. Equivalents acid equals equivalents base.

One usually works the problem in one large step:

### THE EQUIVALENCE METHOD (REDOX)

In redox reactions the entities which are neither created nor destroyed, but which are transferred are the electrons. The number of moles of electrons lost (oxidation numbers gained) by the reducing agent must be equal to the number of moles of electrons gained (oxidation numbers lost) by the oxidizing agent, in exactly the same way that the number of moles of  $H^+$  lost by an acid must be equal to the number of moles of  $H^+$  gained by the base in acid-base reactions. Thus the change in the number of electrons (or change in oxidation number) in a reaction can be the basis for defining equivalents in redox chemistry.

$$\begin{array}{ccc} \text{K}_2\text{Cr}_2\text{O}_7 & \longrightarrow & \text{Cr}^{+3} \\ +6 & & +3 \quad \text{oxidation numbers} \end{array}$$

Note that the above steps constitute only the first part of the procedure commonly used in balancing oxidation-reduction equations. You don't have to complete the equation-balancing procedure in order to use equivalents.

Reducing agent:  $\text{Fe}^{+2} \rightarrow \text{Fe}^{+3}$ , 1 equivalent/mole  
Oxidizing agent:  $\text{MnO}_4^- \rightarrow \text{Mn}^{+2}$ , 5 equiv/mole  
                          +7       +2       oxidation numbers

$$\begin{aligned}
 & (50.0 \text{ ml FeSO}_4 \text{ soln}) \left( \frac{1 \text{ liter FeSO}_4 \text{ soln}}{1000 \text{ ml FeSO}_4 \text{ soln}} \right) \left( \frac{0.100 \text{ moles FeSO}_4}{1 \text{ liter FeSO}_4 \text{ soln}} \right) \cdot \\
 & \cdot \left( \frac{1 \text{ equiv FeSO}_4}{1 \text{ mole FeSO}_4} \right) \left( \frac{1 \text{ mole KMnO}_4}{5 \text{ equiv KMnO}_4} \right) \left( \frac{1}{27.0 \text{ ml KMnO}_4 \text{ soln}} \right) \left( \frac{1000 \text{ ml KMnO}_4 \text{ soln}}{1 \text{ liter KMnO}_4 \text{ soln}} \right) \\
 & = \frac{(50.0)(0.100) \text{ moles KMnO}_4}{(5)(27.0) \text{ liters KMnO}_4 \text{ soln}} = 0.0370 \text{ molar}
 \end{aligned}$$

Note that the term (equiv KMnO<sub>4</sub>) cancels the term (equiv FeSO<sub>4</sub>) because of the definition of the term equivalent. It is not necessary to insert a term  $\left[ \frac{1 \text{ equiv FeSO}_4}{1 \text{ equiv KMnO}_4} \right]$ . (Recall Problem 9).

### NORMALITY

The number of equivalents of a substance contained in a given volume of solution of known concentration is found by multiplying the molarity by the volume (in liters) and then by the integer that converts moles to equivalents. Recall Example 8.

$$\underbrace{\left( \frac{0.500 \text{ moles H}_3\text{PO}_4}{1 \text{ liter H}_3\text{PO}_4 \text{ soln}} \right)}_{\text{Molarity}} \underbrace{(200 \text{ ml H}_3\text{PO}_4 \text{ soln}) \left( \frac{1 \text{ liter H}_3\text{PO}_4 \text{ soln}}{1000 \text{ ml H}_3\text{PO}_4 \text{ soln}} \right)}_{\text{Volume (in liters)}} \underbrace{\left( \frac{3 \text{ equiv H}_3\text{PO}_4}{1 \text{ mole H}_3\text{PO}_4} \right)}_{\text{"integer"}}$$

A new and convenient concentration term, the normality, can be obtained simply by placing the "integer" term first in the multiplication series.

$$\underbrace{\left( \frac{3 \text{ equiv H}_3\text{PO}_4}{1 \text{ mole H}_3\text{PO}_4} \right) \left( \frac{0.500 \text{ moles H}_3\text{PO}_4}{1 \text{ liter H}_3\text{PO}_4 \text{ soln}} \right)}_{\text{Normality}} \underbrace{(200 \text{ ml H}_3\text{PO}_4 \text{ soln}) \left( \frac{1 \text{ liter H}_3\text{PO}_4 \text{ soln}}{1000 \text{ ml H}_3\text{PO}_4 \text{ soln}} \right)}_{\text{Volume (in liters)}}$$

Normality is defined as the number of equivalents of substance per liter of solution, in the same way that molarity is defined as the number of moles of substance per liter of solution. Thus the normality will always be a positive integer times the molarity. You frequently are asked to work problems given normality and volume data (e.g., 200 ml of 1.5 normal H<sub>3</sub>PO<sub>4</sub> in the example above) which simplifies the computation process quite a bit.

**Example 13.** It requires 20.0 ml of 0.0100 molar iodine (I<sub>2</sub>) solution to react completely with 50.0 ml of H<sub>3</sub>AsO<sub>3</sub> solution, the products being I<sup>-</sup> and H<sub>3</sub>AsO<sub>4</sub>. Express the concentration of the I<sub>2</sub> in terms of normality. Calculate the concentration of the arsenious acid solution in terms of both normality and molarity.

Oxidizing agent: I<sub>2</sub> + I<sup>-</sup>, 2 equiv I<sub>2</sub>/mole I<sub>2</sub>  
                           0        -1    oxidation numbers  
                           (1 electron per I, 2 I atoms per I<sub>2</sub>)

Reducing agent: H<sub>3</sub>AsO<sub>3</sub> + H<sub>3</sub>AsO<sub>4</sub>, 2 equiv H<sub>3</sub>AsO<sub>3</sub>/mole H<sub>3</sub>AsO<sub>3</sub>  
                           +3        +5    oxidation numbers

Normality:

$$\left( \frac{0.100 \text{ moles } I_2}{1 \text{ liter } I_2 \text{ soln}} \right) \left( \frac{2 \text{ equiv } I_2}{1 \text{ mole } I_2} \right) = 0.0200 \text{ equiv } I_2 / \text{liter } I_2 \text{ soln}$$

$$= 0.0200 \text{ normal } I_2$$

$$(0.0200 \text{ equiv } I_2)(20.0 \text{ ml } I_2 \text{ soln}) \left( \frac{1 \text{ liter } I_2 \text{ soln}}{1000 \text{ ml } I_2 \text{ soln}} \right) \cdot$$

$$\cdot \left( \frac{1}{50.0 \text{ ml } H_3AsO_3 \text{ soln}} \right) \left( \frac{1000 \text{ ml } H_3AsO_3 \text{ soln}}{1 \text{ liter } H_3AsO_3 \text{ soln}} \right) =$$

$$= \frac{(0.0200)(20.0) \text{ equiv } I_2}{(50.0) \text{ liter } H_3AsO_3 \text{ soln}} = \frac{0.00800 \text{ equiv } H_3AsO_3}{\text{liter } H_3AsO_3 \text{ soln}} = 0.00800 \text{ normal}$$

Note that the term (equiv  $H_3AsO_3$ ) can be substituted for (equiv  $I_2$ ) because of the definition of equivalents.

$$\left( \frac{0.00800 \text{ equiv } H_3AsO_3}{\text{liter } H_3AsO_3 \text{ soln}} \right) \left( \frac{2 \text{ moles } H_3AsO_3}{\text{equiv } H_3AsO_3} \right) = \frac{0.0160 \text{ moles } H_3AsO_3}{\text{liter } H_3AsO_3 \text{ soln}} =$$

$$= 0.0160 \text{ molar.}$$

Using unit analysis with equivalents and normality can be advantageous relative to using moles and molarity when a complete balanced equation is not given, when several substances of the same nature (acids, bases, oxidizing agents, reducing agents) are involved in the same reaction, and when a series of sequential redox equations takes place. Under other circumstances there is no computational advantage in using one method rather than the other.

When using the equivalents method it is absolutely necessary that you know what the products of the reaction are, so that you can determine what the integer is for converting moles to equivalents. If you add HCl to  $Na_2CO_3$  and stop when the indicator phenolphthalein changes color, the product is  $HCO_3^-$ , and you have 1 (equiv  $Na_2CO_3$ /mole  $Na_2CO_3$ ). If you add the HCl until methyl orange changes color, the product is  $H_2CO_3$  (which breaks up into  $H_2O$  and  $CO_2$  which escapes), and you have 2 (equiv  $Na_2CO_3$ /mole  $Na_2CO_3$ ). If you are using  $KMnO_4$  as an oxidizing agent in acid solution, the product is  $Mn^{+2}$ , so there are five equivalents per mole. If you use a basic solution, on the other hand, the product is  $MnO_2$ , so you have three equivalents per mole. Thus concentrations on the labels of laboratory reagents should be in molarity units. A label of 0.600 normal  $KMnO_4$  solution is ambiguous. It could mean either a concentration of 0.120 molar or 0.200 molar.

# Problem Set 1

- 4.465 G OF IMPURE  $\text{KMnO}_4$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.873 M  $\text{Na}_2\text{C}_2\text{O}_4$ .

$$2\text{KMnO}_4 + 5\text{Na}_2\text{C}_2\text{O}_4 + 8\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 10\text{CO}_2 + \text{K}_2\text{SO}_4 + \text{Na}_2\text{SO}_4 + 8\text{H}_2\text{O}$$

AT THE END POINT, THE VOLUME OF  $\text{Na}_2\text{C}_2\text{O}_4$  IS READ AND FOUND TO BE 36.8 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{KMnO}_4$ ?
- WHAT VOLUME (IN ML) OF 0.117 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 77 ML OF 9.596E-01 M  $\text{NaHCO}_3$ ?
- WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 100.0 ML OF THE SOLUTION REQUIRES 34.9 ML OF 0.455 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 2 MOLE OF BASE?
- THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{HCl}$  SOLUTION OCCURS WHEN 18.5 ML OF 0.409 M  $\text{NaOH}$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{NaOH}$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{NaOH}$  WHICH REQUIRES 18.0 ML OF THE SAME  $\text{HCl}$  SOLUTION FOR COMPLETE REACTION?

$$\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2\text{O}$$
- IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 7.362 G OF  $\text{NaOH}$  EACH, WHAT CONCENTRATION OF  $\text{H}_2\text{SO}_4$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?

$$2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$$

ANSWER IN TERMS OF MOLARITY.
- 30.5 ML OF 0.284 M  $\text{KBrO}_3$  IS USED TO TITRATE 50 ML  $\text{KI}$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{KI}$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:

$$\text{KBrO}_3 + 6\text{KI} + 3\text{H}_2\text{SO}_4 = \text{KBr} + 3\text{I}_2 + 3\text{H}_2\text{O} + 3\text{K}_2\text{SO}_4$$

Problem Set 2

1. 15.157 G OF IMPURE  $\text{FeSO}_4$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.389 M  $\text{K}_2\text{Cr}_2\text{O}_7$ .  
$$6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$$
AT THE END POINT, THE VOLUME OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IS READ AND FOUND TO BE 33.0 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{FeSO}_4$  ?
2. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A HCl SOLUTION OCCURS WHEN 33.9 ML OF 0.913 M NaOH HAS BEEN ADDED. HOW MANY GRAMS OF NaOH IS PRESENT IN AN UNKNOWN SAMPLE OF NaOH WHICH REQUIRES 33.2 ML OF THE SAME HCl SOLUTION FOR COMPLETE REACTION?  
$$\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2\text{O}$$
3. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 50.0 ML OF THE SOLUTION REQUIRES 49.2 ML OF 0.978 M ALKALI FOR NEUTRALIZATION IN WHICH 1 MOLE OF ACID REQUIRES 2 MOLE OF BASE?
4. WHAT VOLUME (IN ML) OF 0.996 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 156 ML OF  $9.426 \times 10^{-1}$  M HCN?
5. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 3.132 G OF  $\text{I}_2$  EACH, WHAT CONCENTRATION OF  $\text{Na}_2\text{S}_2\text{O}_3$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
$$\text{I}_2 + 2\text{Na}_2\text{S}_2\text{O}_3 = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}$$
ANSWER IN TERMS OF MOLARITY.
6. 46.6 ML OF 0.733 M  $\text{FeSO}_4$  IS USED TO TITRATE 50 ML  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
$$6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$$

Problem Set 3

1. THE EQUIVALENCENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{KMnO}_4$  SOLUTION OCCURS WHEN 21.7 ML OF 0.375 M  $\text{H}_3\text{AsO}_3$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{H}_3\text{AsO}_3$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{H}_3\text{AsO}_3$  WHICH REQUIRES 27.6 ML OF THE SAME  $\text{KMnO}_4$  SOLUTION FOR COMPLETE REACTION?  
$$5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$$
2. 33.766 G OF IMPURE  $\text{FeSO}_4$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.694 M  $\text{K}_2\text{Cr}_2\text{O}_7$ .  
$$6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$$
AT THE END POINT, THE VOLUME OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IS READ AND FOUND TO BE 38.1 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{FeSO}_4$  ?
3. 42.6 ML OF 0.669 M  $\text{FeSO}_4$  IS USED TO TITRATE 50 ML  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
$$6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$$
4. WHAT VOLUME (IN ML) OF 0.758 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 176 ML OF  $4.826\text{E}-01$  M Benzoic acid?
5. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 1.362 G OF  $\text{NaOH}$  EACH, WHAT CONCENTRATION OF  $\text{H}_2\text{SO}_4$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
$$2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$$
ANSWER IN TERMS OF MOLARITY.
6. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 75.0 ML OF THE SOLUTION REQUIRES 45.9 ML OF 0.535 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 1 MOLE OF BASE?

# Problem Set 4

1. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A HCl SOLUTION OCCURS WHEN 18.9 ML OF 0.481 M NaOH HAS BEEN ADDED. HOW MANY GRAMS OF NaOH IS PRESENT IN AN UNKNOWN SAMPLE OF NaOH WHICH REQUIRES 12.4 ML OF THE SAME HCl SOLUTION FOR COMPLETE REACTION?  
 $\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2\text{O}$
2. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 50.0 ML OF THE SOLUTION REQUIRES 35.8 ML OF 0.819 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 1 MOLE OF BASE?
3. 4.155 G OF IMPURE  $\text{I}_2$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.623 M  $\text{Na}_2\text{S}_2\text{O}_3$ .  
 $\text{I}_2 + 2\text{Na}_2\text{S}_2\text{O}_3 = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}$   
 AT THE END POINT, THE VOLUME OF  $\text{Na}_2\text{S}_2\text{O}_3$  IS READ AND FOUND TO BE 14.2 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{I}_2$  ?
4. WHAT VOLUME (IN ML) OF 0.097 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 181 ML OF  $9.676\text{E}-01$  M HF?
5. 21.7 ML OF 0.373 M  $\text{FeSO}_4$  IS USED TO TITRATE 50 ML  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
 $6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$
6. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 1.972 G OF  $\text{H}_3\text{AsO}_3$  EACH, WHAT CONCENTRATION OF  $\text{KMnO}_4$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
 $5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$   
 ANSWER IN TERMS OF MOLARITY.

Problem Set 5

1. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{H}_2\text{SO}_4$  SOLUTION OCCURS WHEN 25.3 ML OF 0.442 M NaOH HAS BEEN ADDED. HOW MANY GRAMS OF NaOH IS PRESENT IN AN UNKNOWN SAMPLE OF NaOH WHICH REQUIRES 26.2 ML OF THE SAME  $\text{H}_2\text{SO}_4$  SOLUTION FOR COMPLETE REACTION?  
 $2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$
2. 0.481 G OF IMPURE  $\text{I}_2$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.062 M  $\text{Na}_2\text{S}_2\text{O}_3$ .  
 $\text{I}_2 + 2\text{Na}_2\text{S}_2\text{O}_3 = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}$   
AT THE END POINT, THE VOLUME OF  $\text{Na}_2\text{S}_2\text{O}_3$  IS READ AND FOUND TO BE 35.7 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{I}_2$  ?
3. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 5.602 G OF NaOH EACH, WHAT CONCENTRATION OF  $\text{H}_2\text{SO}_4$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
 $2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$   
ANSWER IN TERMS OF MOLARITY.
4. 22.1 ML OF 0.423 M  $\text{H}_3\text{AsO}_3$  IS USED TO TITRATE 50 ML  $\text{KMnO}_4$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{KMnO}_4$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
 $5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$
5. WHAT VOLUME (IN ML) OF 0.794 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 21 ML OF  $8.476\text{E-}01$  M HAc?
6. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 50.0 ML OF THE SOLUTION REQUIRES 18.4 ML OF 0.270 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 1 MOLE OF BASE?

# Problem Set 6

- 22.8 ML OF 0.210 M NaOH IS USED TO TITRATE 50 ML  $\text{H}_2\text{SO}_4$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{H}_2\text{SO}_4$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  

$$2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$$
- IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 2.342 G OF  $\text{KBrO}_3$  EACH, WHAT CONCENTRATION OF KI SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  

$$\text{KBrO}_3 + 6\text{KI} + 3\text{H}_2\text{SO}_4 = \text{KBr} + 3\text{I}_2 + 3\text{H}_2\text{O} + 3\text{K}_2\text{SO}_4$$
  
 ANSWER IN TERMS OF MOLARITY.
- WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 25.0 ML OF THE SOLUTION REQUIRES 10.2 ML OF 0.452 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 1 MOLE OF BASE?
- WHAT VOLUME (IN ML) OF 0.213 M  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 139 ML OF  $7.336\text{E}-01$  M Formic acid?
- THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{KMnO}_4$  SOLUTION OCCURS WHEN 46.0 ML OF 0.439 M  $\text{H}_3\text{AsO}_3$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{H}_3\text{AsO}_3$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{H}_3\text{AsO}_3$  WHICH REQUIRES 33.3 ML OF THE SAME  $\text{KMnO}_4$  SOLUTION FOR COMPLETE REACTION?  

$$5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$$
- 14.475 G OF IMPURE  $\text{H}_3\text{AsO}_3$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.672 M  $\text{KMnO}_4$ .  

$$5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$$
  
 AT THE END POINT, THE VOLUME OF  $\text{KMnO}_4$  IS READ AND FOUND TO BE 36.6 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{H}_3\text{AsO}_3$ ?

Problem Set 7

1. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 7.432 G OF NaOH EACH, WHAT CONCENTRATION OF HCl SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
 $\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2\text{O}$   
ANSWER IN TERMS OF MOLARITY.
2. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 50.0 ML OF THE SOLUTION REQUIRES 26.5 ML OF 0.335 M ALKALI FOR NEUTRALIZATION IN WHICH 1 MOLE OF ACID REQUIRES 2 MOLE OF BASE?
3. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{KMnO}_4$  SOLUTION OCCURS WHEN 26.4 ML OF 0.591 M  $\text{H}_3\text{AsO}_3$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{H}_3\text{AsO}_3$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{H}_3\text{AsO}_3$  WHICH REQUIRES 22.5 ML OF THE SAME  $\text{KMnO}_4$  SOLUTION FOR COMPLETE REACTION?  
 $5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$
4. WHAT VOLUME (IN ML) OF 0.767 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 6 ML OF  $7.926\text{E}-01$  M  $\text{HClO}_4$ ?
5. 9.509 G OF IMPURE  $\text{H}_3\text{AsO}_3$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.166 M  $\text{KMnO}_4$ .  
 $5\text{H}_3\text{AsO}_3 + 2\text{KMnO}_4 + 3\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 5\text{H}_3\text{AsO}_4 + \text{K}_2\text{SO}_4 + 3\text{H}_2\text{O}$   
AT THE END POINT, THE VOLUME OF  $\text{KMnO}_4$  IS READ AND FOUND TO BE 26.3 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{H}_3\text{AsO}_3$ ?
6. 39.4 ML OF 0.593 M NaOH IS USED TO TITRATE 50 ML HCl SOLUTION. CALCULATE THE NUMBER OF MMOLES OF HCl IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
 $\text{NaOH} + \text{HCl} = \text{NaCl} + \text{H}_2\text{O}$

# Problem Set 8

1. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 50.0 ML OF THE SOLUTION REQUIRES 13.5 ML OF 1.005 M ALKALI FOR NEUTRALIZATION IN WHICH 1 MOLE OF ACID REQUIRES 1 MOLE OF BASE?
2. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 1.482 G OF  $\text{KMnO}_4$  EACH, WHAT CONCENTRATION OF  $\text{Na}_2\text{C}_2\text{O}_4$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
 $2\text{KMnO}_4 + 5\text{Na}_2\text{C}_2\text{O}_4 + 8\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 10\text{CO}_2 + \text{K}_2\text{SO}_4 + \text{Na}_2\text{SO}_4 + 8\text{H}_2\text{O}$   
 ANSWER IN TERMS OF MOLARITY.
3. 15.5 ML OF 0.189 M  $\text{FeSO}_4$  IS USED TO TITRATE 50 ML  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION. CALCULATE THE NUMBER OF MMOLIES OF  $\text{K}_2\text{Cr}_2\text{O}_7$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
 $6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$
4. WHAT VOLUME (IN ML) OF 0.892 M  $\text{KOH}$  WILL BE REQUIRED TO REACT COMPLETELY WITH 132 ML OF 2.9461-01 M  $\text{HF}$ ?
5. 2.100 G OF IMPURE  $\text{KMnO}_4$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.058 M  $\text{Na}_2\text{C}_2\text{O}_4$ .  
 $2\text{KMnO}_4 + 5\text{Na}_2\text{C}_2\text{O}_4 + 8\text{H}_2\text{SO}_4 = 2\text{MnSO}_4 + 10\text{CO}_2 + \text{K}_2\text{SO}_4 + \text{Na}_2\text{SO}_4 + 8\text{H}_2\text{O}$   
 AT THE END POINT, THE VOLUME OF  $\text{Na}_2\text{C}_2\text{O}_4$  IS READ AND FOUND TO BE 45.6 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{KMnO}_4$ ?
6. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{KI}$  SOLUTION OCCURS WHEN 24.5 ML OF 0.204 M  $\text{KBrO}_3$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{KBrO}_3$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{KBrO}_3$  WHICH REQUIRES 44.7 ML OF THE SAME  $\text{KI}$  SOLUTION FOR COMPLETE REACTION?  
 $\text{KBrO}_3 + 6\text{KI} + 3\text{H}_2\text{SO}_4 = \text{KBr} + 3\text{I}_2 + 3\text{H}_2\text{O} + 3\text{K}_2\text{SO}_4$

# Problem Set 9

1. THE EQUIVALENCY POINT IN A TITRATION OF A 25 ML PORTION OF A  $K_2Cr_2O_7$  SOLUTION OCCURS WHEN 31.4 ML OF 0.637 M  $FeSO_4$  HAS BEEN ADDED. HOW MANY GRAMS OF  $FeSO_4$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $FeSO_4$  WHICH REQUIRES 21.2 ML OF THE SAME  $K_2Cr_2O_7$  SOLUTION FOR COMPLETE REACTION?  
 $6FeSO_4 + K_2Cr_2O_7 + 7H_2SO_4 = Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O$
2. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 1.912 G OF  $NaOH$  EACH, WHAT CONCENTRATION OF  $HCl$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
 $NaOH + HCl = NaCl + H_2O$   
 ANSWER IN TERMS OF MOLARITY.
3. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 75.0 ML OF THE SOLUTION REQUIRES 34.4 ML OF 0.291 M ALKALI FOR NEUTRALIZATION IN WHICH 1 MOLE OF ACID REQUIRES 2 MOLE OF BASE?
4. 36.5 ML OF 0.795 M  $I_2$  IS USED TO TITRATE 50 ML  $Na_2S_2O_3$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $Na_2S_2O_3$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
 $I_2 + 2Na_2S_2O_3 = Na_2S_4O_6 + 2NaI$
5. WHAT VOLUME (IN ML) OF 0.117 M  $Ca(OH)_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 174 ML OF  $5.286E-01$  M Formic acid?
6. 7.578 G OF IMPURE  $KMnO_4$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.483 M  $Na_2C_2O_4$ .  
 $2KMnO_4 + 5Na_2C_2O_4 + 8H_2SO_4 = 2MnSO_4 + 10CO_2 + K_2SO_4 + Na_2SO_4 + 8H_2O$   
 AT THE END POINT, THE VOLUME OF  $Na_2C_2O_4$  IS READ AND FOUND TO BE 18.5 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $KMnO_4$  ?

Problem Set 10

1. WHAT IS THE MOLARITY OF AN ACID SOLUTION IF 75.0 ML OF THE SOLUTION REQUIRES 9.5 ML OF 0.611 M ALKALI FOR NEUTRALIZATION IN WHICH 2 MOLE OF ACID REQUIRES 2 MOLE OF BASE?
2. 45.3 ML OF 0.826 M NaOH IS USED TO TITRATE 50 ML  $\text{H}_2\text{SO}_4$  SOLUTION. CALCULATE THE NUMBER OF MMOLES OF  $\text{H}_2\text{SO}_4$  IN THE SOLUTION. THE CHEMICAL EQUATION IS:  
$$2\text{NaOH} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$$
3. IF ANALYSES ARE TO BE RUN ON SAMPLES CONTAINING APPROXIMATELY 4.572 G OF  $\text{I}_2$  EACH, WHAT CONCENTRATION OF  $\text{Na}_2\text{S}_2\text{O}_3$  SOLUTION SHOULD BE CHOSEN SO THAT EACH TITRATION TAKES ABOUT 35.0 ML?  
$$\text{I}_2 + 2\text{Na}_2\text{S}_2\text{O}_3 = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}$$
  
ANSWER IN TERMS OF MOLARITY.
4. 1.913 G OF IMPURE  $\text{KBrO}_3$  SAMPLE IS WEIGHED OUT, AND DISSOLVED IN AN ACID SOLUTION. THIS SOLUTION IS TITRATED WITH 0.969 M KI.  
$$\text{KBrO}_3 + 6\text{KI} + 3\text{H}_2\text{SO}_4 = \text{KBr} + 3\text{I}_2 + 3\text{H}_2\text{O} + 3\text{K}_2\text{SO}_4$$
  
AT THE END POINT, THE VOLUME OF KI IS READ AND FOUND TO BE 45.0 ML. WHAT PERCENTAGE OF THE SAMPLE WAS  $\text{KBrO}_3$ ?
5. WHAT VOLUME (IN ML) OF 0.232 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 133 ML OF  $4.716\text{E-}01$  M HP?
6. THE EQUIVALENCE POINT IN A TITRATION OF A 25 ML PORTION OF A  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION OCCURS WHEN 45.3 ML OF 0.365 M  $\text{FeSO}_4$  HAS BEEN ADDED. HOW MANY GRAMS OF  $\text{FeSO}_4$  IS PRESENT IN AN UNKNOWN SAMPLE OF  $\text{FeSO}_4$  WHICH REQUIRES 36.7 ML OF THE SAME  $\text{K}_2\text{Cr}_2\text{O}_7$  SOLUTION FOR COMPLETE REACTION?  
$$6\text{FeSO}_4 + \text{K}_2\text{Cr}_2\text{O}_7 + 7\text{H}_2\text{SO}_4 = \text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 7\text{H}_2\text{O}$$

Problem Set 11

1. WHAT WEIGHT OF  $\text{Co}^{+3}$  IS NEEDED TO REACT WITH 0.890 G OF  $\text{Cu}^{+}$ ?  
THE PRODUCTS OF THE REACTION ARE  $\text{Co}^{++}$  AND  $\text{Cu}^{++}$ .
2. 39.9 ML OF A 0.935 NORMAL  $\text{Cu}^{++}$  SOLUTION IS REQUIRED  
TO TITRATE 9.3 ML OF A  $\text{Ti}^{+3}$  SOLUTION. HOW MANY  
GRAMS OF  $\text{Ti}^{+3}$  PER LITER WAS IN THE SOLUTION?  
THE PRODUCTS OF THE REACTION WERE  $\text{Cu}^{+}$  AND  $\text{TiO}^{++}$ .
3. GIVEN THE FOLLOWING REACTION:  
$$\text{V}^{++} + \text{TiO}^{++} + 2 \text{H}^{+} = \text{Ti}^{+3} + \text{H}_2\text{O} + \text{V}^{+3}$$
  
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{TiO}^{++}$  AND  $\text{V}^{+3}$   
FOR THIS REACTION?
4. HOW MANY GRAMS OF  $\text{Mn}^{++}$  IS NEEDED TO MAKE  
448 ML OF A 0.547 NORMAL SOLUTION FOR A REACTION  
IN WHICH  $\text{Mn}^{++}$  GOES TO  $\text{MnO}_4^{-}$  ?
5. WHAT VOLUME (IN ML) OF 0.566 N  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY  
WITH 78 ML OF  $1.356 \times 10^{-1}$  N Formic acid?

Problem Set 12

1. 46.8 ML OF A 0.757 NORMAL  $\text{Ti}^{3+}$  SOLUTION IS REQUIRED TO TITRATE 41.3 ML OF A  $\text{I}^-$  SOLUTION. HOW MANY GRAMS OF  $\text{I}^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Ti}^{4+}$  AND  $\text{I}_2$ .
2. HOW MANY GRAMS OF  $\text{H}_2\text{S}(\text{aq})$  IS NEEDED TO MAKE 450 ML OF A 0.959 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{H}_2\text{S}(\text{aq})$  GOES TO S ?
3. GIVEN THE FOLLOWING REACTION:  
$$2 \text{I}^- + \text{Cl}_2 = 2 \text{Cl}^- + \text{I}_2$$
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Cl}_2$  AND  $\text{I}^-$  FOR THIS REACTION?
4. WHAT WEIGHT OF  $\text{Hg}^{++}$  IS NEEDED TO REACT WITH 0.927 G OF  $\text{Sn}^{++}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Hg}_2^{++}$  AND  $\text{Sn}^{4+}$ .
5. WHAT VOLUME(IN ML) OF 0.652 M  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 100 ML OF  $3.062 \times 10^{-2}$  M Propionic acid?

Problem Set 13

1. WHAT VOLUME (IN ML) OF 0.441 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 53 ML OF  $7.116 \times 10^{-1}$  M  $\text{HClO}_2$ ?
2. HOW MANY GRAMS OF  $\text{Mn}^{++}$  IS NEEDED TO MAKE 347 ML OF A 0.405 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{Mn}^{++}$  GOES TO  $\text{MnO}_4^-$ ?
3. WHAT WEIGHT OF  $\text{H}_2\text{IO}_4$  IS NEEDED TO REACT WITH 0.890 G OF  $\text{Hg}_2^{++}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{IO}_3^-$  AND  $\text{Hg}^{++}$ .
4. GIVEN THE FOLLOWING REACTION:  
$$\text{Tl}^+ + 2 \text{Co}^{+3} = 2 \text{Co}^{++} + \text{Tl}^{+3}$$
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Co}^{+3}$  AND  $\text{Tl}^+$  FOR THIS REACTION?
5. 27.0 ML OF A 0.902 NORMAL  $\text{NO}_3^-$  SOLUTION IS REQUIRED TO TITRATE 38.1 ML OF A  $\text{I}^-$  SOLUTION. HOW MANY GRAMS OF  $\text{I}^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{NO}$  AND  $\text{I}_2$ .

Problem Set 14

1. WHAT WEIGHT OF  $I_2$  IS NEEDED TO REACT WITH 0.948 G OF  $V^{++}$ ?  
THE PRODUCTS OF THE REACTION ARE  $I^-$  AND  $V^{+3}$ .
2. WHAT VOLUME (IN ML) OF 0.825 M  $Ba(OH)_2$  WILL BE REQUIRED TO REACT COMPLETELY  
WITH 52 ML OF  $9.346 \times 10^{-1}$  M  $HCN$ ?
3. HOW MANY GRAMS OF  $H_2S(aq)$  IS NEEDED TO MAKE  
474 ML OF A 0.563 NORMAL SOLUTION FOR A REACTION  
IN WHICH  $H_2S(aq)$  GOES TO S ?
4. GIVEN THE FOLLOWING REACTION:  

$$Mn^{++} + 4 H_2O + 5 Co^{+3} = 5 Co^{++} + MnO_4^- + 8 H^+$$
 WHAT ARE THE EQUIVALENT WEIGHTS OF  $Co^{+3}$  AND  $Mn^{++}$   
FOR THIS REACTION?
5. 57.6 ML OF A 0.791 NORMAL  $I_2$  SOLUTION IS REQUIRED  
TO TITRATE 14.7 ML OF A  $V^{++}$  SOLUTION. HOW MANY  
GRAMS OF  $V^{++}$  PER LITER WAS IN THE SOLUTION?  
THE PRODUCTS OF THE REACTION WERE  $I^-$  AND  $V^{+3}$ .

Problem Set 15

1. HOW MANY GRAMS OF  $\text{Mn}^{++}$  IS NEEDED TO MAKE  
305 ML OF A 0.720 NORMAL SOLUTION FOR A REACTION  
IN WHICH  $\text{Mn}^{++}$  GOES TO  $\text{MnO}_4^-$  ?
2. GIVEN THE FOLLOWING REACTION:  
 $2 \text{S}_2\text{O}_3^{--} + 2 \text{Ce}^{++} = 2 \text{Ce}^{+3} + \text{S}_4\text{O}_6^{--}$   
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Ce}^{++}$  AND  $\text{S}_2\text{O}_3^{--}$   
FOR THIS REACTION?
3. WHAT VOLUME (IN ML) OF 0.537 N  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY  
WITH 29 ML OF  $6.636 \times 10^{-1}$  N  $\text{NaHCO}_3$ ?
4. WHAT WEIGHT OF  $\text{Ce}^{++}$  IS NEEDED TO REACT WITH 0.709 G OF  $\text{Ti}^{+3}$ ?  
THE PRODUCTS OF THE REACTION ARE  $\text{Ce}^{+3}$  AND  $\text{TiO}^{++}$ .
5. 45.5 ML OF A 0.367 NORMAL  $\text{MnO}_4^-$  SOLUTION IS REQUIRED  
TO TITRATE 8.9 ML OF A  $\text{V}^{++}$  SOLUTION. HOW MANY  
GRAMS OF  $\text{V}^{++}$  PER LITER WAS IN THE SOLUTION?  
THE PRODUCTS OF THE REACTION WERE  $\text{Mn}^{++}$  AND  $\text{V}^{+3}$ .

Problem Set 16

1. WHAT VOLUME(IN ML) OF 0.525 M  $\text{Ca(OH)}_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 67 ML OF  $1.896 \times 10^{-1}$  M Propionic acid?
2. WHAT WEIGHT OF  $\text{S}_2\text{O}_8^{--}$  IS NEEDED TO REACT WITH 0.310 G OF  $\text{Ti}^{+3}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{SO}_4^{--}$  AND  $\text{Ti}^{+3}$ .
3. GIVEN THE FOLLOWING REACTION:  
$$2 \text{Br}^- + 2 \text{Ce}^{++} = 2 \text{Ce}^{+3} + \text{Br}_2(\text{aq})$$
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Ce}^{++}$  AND  $\text{Br}^-$  FOR THIS REACTION?
4. HOW MANY GRAMS OF  $\text{IO}_3^-$  IS NEEDED TO MAKE 348 ML OF A 0.547 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{IO}_3^-$  GOES TO  $\text{H}_2\text{IO}_4$  ?
5. 20.7 ML OF A 0.069 NORMAL  $\text{I}_2$  SOLUTION IS REQUIRED TO TITRATE 29.1 ML OF A  $\text{Ti}^{+3}$  SOLUTION. HOW MANY GRAMS OF  $\text{Ti}^{+3}$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{I}^-$  AND  $\text{TiO}^{++}$ .

Problem Set 17

1. 44.7 ML OF A 0.371 NORMAL  $\text{H}_5\text{IO}_6$  SOLUTION IS REQUIRED TO TITRATE 36.4 ML OF A  $\text{Cu}^+$  SOLUTION. HOW MANY GRAMS OF  $\text{Cu}^+$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{IO}_3^-$  AND  $\text{Cu}^{++}$ .
2. HOW MANY GRAMS OF  $\text{Ag}^+$  IS NEEDED TO MAKE 142 ML OF A 0.297 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{Ag}^+$  GOES TO  $\text{Ag}^{++}$  ?
3. GIVEN THE FOLLOWING REACTION:  
$$\text{H}_2\text{S}(\text{aq}) + \text{S}_2\text{O}_8^{--} = 2 \text{SO}_4^{--} + \text{S} + 2 \text{H}^+$$
  
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{S}_2\text{O}_8^{--}$  AND  $\text{H}_2\text{S}(\text{aq})$  FOR THIS REACTION?
4. WHAT WEIGHT OF  $\text{Br}_2(\text{aq})$  IS NEEDED TO REACT WITH 0.214 G OF  $\text{S}_2\text{O}_3^{--}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Br}^-$  AND  $\text{S}_4\text{O}_6^{--}$ .
5. WHAT VOLUME (IN ML) OF 0.159 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 45 ML OF 6.956E-01 M  $\text{NaHCO}_3$ ?

Problem Set 18

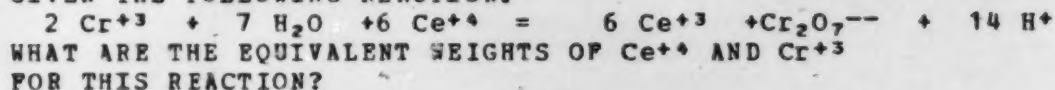
1. WHAT VOLUME (IN ML) OF 0.532 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 40 ML OF  $4.106 \times 10^{-1}$  M  $\text{HNO}_2$ ?
2. GIVEN THE FOLLOWING REACTION:  
$$\text{Hg}_2^{++} + \text{H}_5\text{IO}_6 + \text{H}^+ = \text{IO}_3^- + 3 \text{H}_2\text{O} + 2 \text{Hg}^{++}$$
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{H}_5\text{IO}_6$  AND  $\text{Hg}_2^{++}$  FOR THIS REACTION?
3. 12.1 ML OF A 0.686 NORMAL  $\text{Cl}_2$  SOLUTION IS REQUIRED TO TITRATE 8.2 ML OF A  $\text{Ti}^{+3}$  SOLUTION. HOW MANY GRAMS OF  $\text{Ti}^{+3}$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Cl}^-$  AND  $\text{TiO}^{++}$ .
4. HOW MANY GRAMS OF  $\text{Ti}^+$  IS NEEDED TO MAKE 81 ML OF A 0.865 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{Ti}^+$  GOES TO  $\text{Ti}^{+3}$ ?
5. WHAT WEIGHT OF  $\text{Ag}^{++}$  IS NEEDED TO REACT WITH 0.454 G OF  $\text{V}^{++}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Ag}^+$  AND  $\text{V}^{+3}$ .

Problem Set 19

1. 58.7 ML OF A 0.434 NORMAL  $\text{Hg}^{++}$  SOLUTION IS REQUIRED TO TITRATE 11.9 ML OF A  $\text{Cu}^+$  SOLUTION. HOW MANY GRAMS OF  $\text{Cu}^+$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Hg}_2^{++}$  AND  $\text{Cu}^{++}$ .
2. HOW MANY GRAMS OF  $\text{Br}^-$  IS NEEDED TO MAKE 23 ML OF A 0.867 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{Br}^-$  GOES TO  $\text{Br}_2(\text{aq})$  ?
3. WHAT WEIGHT OF  $\text{Ag}^{++}$  IS NEEDED TO REACT WITH 0.762 G OF  $\text{Ti}^+$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Ag}^+$  AND  $\text{Ti}^{+3}$ .
4. WHAT VOLUME (IN ML) OF 0.601 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 132 ML OF  $6.946\text{E}-01$  M  $\text{NaHSO}_3$ ?
5. GIVEN THE FOLLOWING REACTION:  
$$2 \text{I}^- + \text{S}_2\text{O}_8^{--} = 2 \text{SO}_4^{--} + \text{I}_2$$
WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{S}_2\text{O}_8^{--}$  AND  $\text{I}^-$  FOR THIS REACTION?

Problem Set 20

1. GIVEN THE FOLLOWING REACTION:



2. 56.7 ML OF A 0.587 NORMAL  $\text{MnO}_4^-$  SOLUTION IS REQUIRED TO TITRATE 22.6 ML OF A  $\text{Cl}^-$  SOLUTION. HOW MANY GRAMS OF  $\text{Cl}^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Mn}^{++}$  AND  $\text{Cl}_2$ .
3. WHAT VOLUME (IN ML) OF 0.239 M  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 53 ML OF  $9.116\text{E}-01$  M Propionic acid?
4. WHAT WEIGHT OF  $\text{Co}^{+3}$  IS NEEDED TO REACT WITH 0.574 G OF  $\text{NO}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Co}^{++}$  AND  $\text{NO}_3^-$ .
5. HOW MANY GRAMS OF  $\text{I}^-$  IS NEEDED TO MAKE 93 ML OF A 0.972 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{I}^-$  GOES TO  $\text{I}_2$  ?

### The CM Project

The Computer-enriched Module (CM) project is a collaborative effort by 19 faculty members in the disciplines of chemistry, mathematics and physics, to produce self-instructional computer-based materials at the introductory college level in those disciplines. Each module is designed to be usable in an academic environment with minimal computational facilities, and by students and faculty who are not programming experts. It may be used as an adjunct to standard textual materials, or in many cases, as a replacement for them. The primary aim of each module is to use the computer in such a way that students may take a more active role in the development and discovery of concepts and phenomena.

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TEACHER'S GUIDE TO  
A MODULE ON SOLUTIONS  
UNIT 4. SOLUTION STOICHIOMETRY

RICHARD T. O'NEILL  
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a computer-enriched module  
for introductory chemistry  
featuring the program  
ENDPT

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TEACHER'S GUIDE TO UNIT ON SOLUTION STOICHIOMETRY  
OF THE SOLUTIONS MODULE

EDUCATIONAL OBJECTIVES

In this section the student learns to work solution stoichiometry problems where there are no limiting reagent complications. The method uses the unit analysis approach begun in the Stoichiometry module and last seen by the student in the Dilution Unit of the Solutions module which immediately precedes this unit.

The first part of the unit -- ending with the computer assignment on page 4 -- works problems in terms of moles, molarity, and balanced chemical equations. It does not assume background in acid-base or redox reactions, merely that two reagents react in a chemical equation. This part will take approximately one hour. The instructor should assign one of the problem sets numbered 1-10, which will take an additional  $1/2 - 1$  hr.

The second part of the unit -- beginning on page 4 -- works problems in terms of equivalents and normality. Although sufficient concepts are introduced within the unit to cover the acid-base aspects of equivalents, the concept of oxidation number is assumed for the redox aspects.

IMPLEMENTATION

The unit is constructed so that the second part may be skipped (if the students are not to learn about normality or equivalents) or delayed (if the instructor has not yet covered oxidation state). The second part will take approximately one hour. The instructor should assign one of the problem sets 11-20, which will take an additional  $1/2 - 1$  hr.

## ANSWERS TO PROBLEM SETS

TEST 1

1.  $4.55E+01$ 2.  $3.16E+02$ 3.  $1.59E-01$ 4.  $2.18E-01$ 5.  $2.63E+00$ 6.  $5.19E+01$ 

TEST 2

1.  $8.88E+01$ 2.  $1.64E+00$ 3.  $4.81E-01$ 4.  $7.38E+01$ 5.  $7.05E-01$ 6.  $5.69E+00$ 

TEST 3

1.  $1.13E+00$ 2.  $7.13E+01$ 3.  $4.75E+00$ 4.  $5.60E+01$ 5.  $4.87E-01$ 6.  $6.54E-01$

| TEST 4      | TEST 5      | TEST 6      |
|-------------|-------------|-------------|
| 1. 1.80E-01 | 1. 4.69E-01 | 1. 2.39E+00 |
| 2. 1.17E+00 |             | 2. 2.39E+00 |
|             | 2. 5.83E+01 | 3. 3.69E-01 |
| 3. 2.71E+01 |             | 4. 2.39E+02 |
| 4. 1.81E+03 | 3. 2.00E+00 |             |
|             | 4. 3.74E+00 | 5. 3.39E+00 |
| 5. 1.35E+00 | 5. 2.24E+01 |             |
| 6. 1.79E-01 | 6. 1.98E-01 | 6. 5.35E+01 |

| TEST 7      | TEST 8      | TEST 9      | TEST 10     |
|-------------|-------------|-------------|-------------|
|             | 1. 2.70E-01 |             | 1. 7.74E-02 |
| 1. 5.31E+00 |             | 1. 2.58E+00 |             |
|             | 2. 6.70E-01 |             | 2. 1.87E+01 |
| 2. 8.86E-02 |             | 2. 1.37E+00 |             |
|             | 3. 4.87E-01 |             | 3. 1.03E+00 |
| 3. 1.77E+00 | 4. 4.36E+01 | 3. 6.67E-02 |             |
| 4. 3.10E+00 |             | 4. 5.81E+01 | 4. 6.37E+01 |
|             | 5. 7.94E+00 | 5. 3.93E+02 | 5. 2.70E+02 |
| 5. 1.44E+01 |             |             |             |
| 6. 2.33E+01 | 6. 1.50E+00 | 6. 7.44E+00 | 6. 3.69E+00 |

## TEST 11

1. 8.25E-01 G

2. 1.92E+02

3. 63.90 50.90

4. 2.69E+00

5. 9.41E+00

## TEST 12

1. 1.09E+02

2. 7.34E+00

3. 34.95 126.90

4. 3.13E+00 G

5. 2.35E+00

## TEST 13

1. 4.28E+01

2. 1.54E+00

3. 5.06E-01 G

4. 58.93 102.20

5. 8.11E+01

## TEST 14

1. 2.36E+00 G

2. 2.95E+01

3. 4.54E+00

4. 58.93 10.98

5. 1.58E+02

## TEST 15

1. 2.41E+00

2. 140.10 112.00

3. 1.79E+01

4. 2.07E+00 G

5. 9.55E+01

## TEST 16

1. 1.21E+01

2. 2.91E-01 G

3. 140.10 79.90

4. 1.66E+01

5. 2.35E+00

## TEST 17

1.  $2.90E+01$ 2.  $4.55E+00$ 

## TEST 18

1.  $3.09E+01$ 

2. 113.95 200.60

3.  $4.85E+01$ 4.  $7.16E+00$ 5.  $9.62E-01$  G

## TEST 19

1.  $1.36E+02$ 2.  $1.59E+00$ 3.  $8.04E-01$  G4.  $1.53E+02$ 

5. 96.00 126.90

## TEST 20

1. 140.10 17.33

2.  $5.22E+01$ 3.  $1.01E+02$ 4.  $3.38E+00$  G5.  $1.15E+01$

## SOFTWARE

The program ENDPT does not explicitly ask the student to go through the conversion process, since this was done extensively in the examples and performed in detail in the program DILUTE in the previous unit. Instead, it merely presents the conversion calculation after the needed data has been obtained from a simulated experiment.

The program uses a game format to discover the volume of strong base of known molarity needed to exactly neutralize an aliquot of acid of unknown concentration.

This program prepares the student for his initial exposure to laboratory titration using an indicator-determined endpoint. No provision is made for back titration with either known base or unknown acid, but it nonetheless breaks down the student's fear of "wasting" a sample, gives him some idea of the accuracy attainable by titration, and shows him how to manipulate his laboratory data. The instructor should emphasize that the specific costs assumed by the program may not be particularly realistic and that in the object "to get precise results at minimum cost" the emphasis is on the precise results. Of course, the minimum cost obtained should not be used in computing his grade.

### Extensions

The instructor may wish to give brighter students more advanced problems in which:

- a) a solid reagent is titrated,
- b) an impure reagent is titrated (yielding a percentage purity answer),
- c) back titration is involved.

A brighter student may also wish to write computer programs involving titration, examples of which can be found in "Introduction to Computer Programming for Chemists -- BASIC Version" by C. Wilkins et. al. (Chapters 12, 13, 15, 16, 18). These involve weak acids or bases, however, and may not be appropriate at this time.

RUN                   ENDPT Sample Run  
 ENDPT   09:34           24-JUN-75  
           ENDPT    TITRATION SIMULATION GAME

DO YOU WISH INSTRUCTIONS (YES OR NO) ? YES

YOU ARE GIVEN A LARGE SUPPLY OF STANDARD NAOH SOLUTION OF KNOWN MOLARITY, AND A 50-ML BURET TO DISPENSE IT WITH. YOU CAN GET 25.00 ML SAMPLES OF HYDROCHLORIC ACID OF UNKNOWN MOLARITY. THE OBJECT OF THIS GAME IS TO EFFICIENTLY FIND THE MOLARITY OF THIS ACID BY TITRATING SAMPLES OF IT WITH THE BASE. AN INDICATOR ADDED TO THE SOLUTION WILL CHANGE COLOR WHEN YOU PASS THE EQUIVALENCE (END) POINT AND THE SOLUTION BECOMES BASIC. YOU MUST ATTAIN ANALYTICAL PRECISION - - I.E. THE SOLUTION MUST CHANGE COLOR WHEN ONLY ONE DROP (.05 ML) IS ADDED.

THE BEST STRATEGY IS **\*\*NOT\*\*** TO ADD SUCCESSIVE .05 ML PORTIONS IN THE FIRST TITRATION. ALTHOUGH CHEMICALS COST MONEY (ABOUT 1 CENT/ML FOR STANDARD BASE, 9 CENTS FOR A SAMPLE OF UNKNOWN ACID, 1 CENT FOR A DROP OF INDICATOR) YOUR TIME IS VALUABLE TOO. IF YOU ARE PAID \$12/HR., IT COSTS ABOUT 5 CENTS TO TAKE A BURET READING, 20 CENTS TO REFILL A BURET, AND 10 CENTS TO PIPETTE OUT A 25.00 ML SAMPLE OF ACID. THE OBJECT OF THIS GAME IS TO ATTAIN ANALYTICAL RESULTS AT **\*\*MINIMUM COST\*\***. WORK OUT YOUR OWN STRATEGY FOR DOING THIS BY TITRATING MORE THAN ONE SAMPLE.

IT HAS ALREADY COST YOU \$0.60 TO RINSE OUT THE BURET THREE TIMES WITH 10 ML PORTIONS OF THE BASE.

YOUR STANDARD BASE IS 0.1255 MOLAR.

YOU HAVE JUST OBTAINED YOUR FIRST SAMPLE OF 25.00 ML OF AN HCL SOLUTION OF UNKNOWN CONCENTRATION, AND FILLED UP YOUR BURET WITH STANDARDIZED NAOH SOLUTION.

THIS IS TITRATION # 1 FOR THIS ACID.

| VOL.(ML) | TOT.COST |                             |
|----------|----------|-----------------------------|
| 0.00     | \$1.00   | ML BASE ADD NEXT? <u>10</u> |
| 10.00    | \$1.15   | ML BASE ADD NEXT? <u>-2</u> |

NICE TRY, BUT YOU CAN'T SUBTRACT BASE ALREADY ADDED.

|       |        |                              |
|-------|--------|------------------------------|
| 10.00 | \$1.15 | ML BASE ADD NEXT? <u>.01</u> |
|-------|--------|------------------------------|

DON'T KID YOURSELF. YOU HAVEN'T PRACTICED TITRATION ENOUGH YET TO BE ABLE TO SPLIT DROPS. A MINIMUM OF .05 ML MUST BE ADDED.

|       |        |                              |
|-------|--------|------------------------------|
| 10.00 | \$1.15 | ML BASE ADD NEXT? <u>.45</u> |
|-------|--------|------------------------------|

YOU HAVE DRAINED THE BURET BEYOND THE MARK WHERE YOU CAN READ IT. THIS RUN IS RUINED.

THIS IS TITRATION # 2 FOR THIS ACID.

| VOL.(ML) | TOT.COST |                             |
|----------|----------|-----------------------------|
| 0.00     | \$1.95   | ML BASE ADD NEXT? <u>10</u> |
| 10.00    | \$2.10   | ML BASE ADD NEXT? <u>1</u>  |
| 11.00    | \$2.16   | ML BASE ADD NEXT? <u>1</u>  |
| 12.00    | \$2.22   | ML BASE ADD NEXT? <u>1</u>  |
| 13.00    | \$2.28   | ML BASE ADD NEXT? <u>1</u>  |
| 14.00    | \$2.34   | ML BASE ADD NEXT? <u>1</u>  |

|       |        |                   |          |
|-------|--------|-------------------|----------|
| 15.00 | \$2.40 | ML BASE ADD NEXT? | <u>1</u> |
| 16.00 | \$2.46 | ML BASE ADD NEXT? | <u>1</u> |
| 17.00 | \$2.52 | ML BASE ADD NEXT? | <u>1</u> |
| 18.00 | \$2.58 | ML BASE ADD NEXT? | <u>1</u> |
| 19.00 | \$2.64 | ML BASE ADD NEXT? | <u>1</u> |
| 20.00 | \$2.70 | ML BASE ADD NEXT? | <u>1</u> |
| 21.00 | \$2.76 | ML BASE ADD NEXT? | <u>1</u> |
| 22.00 | \$2.82 | ML BASE ADD NEXT? | <u>1</u> |
| 23.00 | \$2.88 | ML BASE ADD NEXT? | <u>1</u> |
| 24.00 | \$2.94 | ML BASE ADD NEXT? | <u>1</u> |
| 25.00 | \$3.00 | ML BASE ADD NEXT? | <u>1</u> |
| 26.00 | \$3.06 | ML BASE ADD NEXT? | <u>1</u> |
| 27.00 | \$3.12 | ML BASE ADD NEXT? | <u>1</u> |
| 28.00 | \$3.18 | ML BASE ADD NEXT? | <u>1</u> |
| 29.00 | \$3.24 | ML BASE ADD NEXT? | <u>1</u> |
| 30.00 | \$3.30 | ML BASE ADD NEXT? | <u>1</u> |
| 31.00 | \$3.36 | ML BASE ADD NEXT? | <u>1</u> |
| 32.00 | \$3.42 | ML BASE ADD NEXT? | <u>1</u> |
| 33.00 | \$3.48 | ML BASE ADD NEXT? | <u>1</u> |
| 34.00 | \$3.54 | ML BASE ADD NEXT? | <u>1</u> |
| 35.00 | \$3.60 | ML BASE ADD NEXT? | <u>1</u> |
| 36.00 | \$3.66 | ML BASE ADD NEXT? | <u>1</u> |
| 37.00 | \$3.72 | ML BASE ADD NEXT? | <u>1</u> |
| 38.00 | \$3.78 | ML BASE ADD NEXT? | <u>1</u> |
| 39.00 | \$3.84 | ML BASE ADD NEXT? | <u>1</u> |
| 40.00 | \$3.90 | ML BASE ADD NEXT? | <u>1</u> |
| 41.00 | \$3.96 | ML BASE ADD NEXT? | <u>1</u> |
| 42.00 | \$4.02 | ML BASE ADD NEXT? | <u>1</u> |
| 43.00 | \$4.08 | ML BASE ADD NEXT? | <u>1</u> |
| 44.00 | \$4.14 | ML BASE ADD NEXT? | <u>1</u> |

THE INDICATOR HAS CHANGED COLOR. THE BASE IS NOW IN EXCESS.  
THE LAST VOLUME YOU ADDED WAS MORE THAN ONE DROP  
(.05 ML) SO YOU'LL HAVE TO GET ANOTHER SAMPLE OF ACID.

THIS IS TITRATION # 3 FOR THIS ACID.

| VOL.(ML) | TOT.COST |                              |
|----------|----------|------------------------------|
| 0.00     | \$4.60   | ML BASE ADD NEXT? <u>44</u>  |
| 44.00    | \$5.09   | ML BASE ADD NEXT? <u>.05</u> |
| 44.05    | \$5.14   | ML BASE ADD NEXT? <u>.05</u> |
| 44.10    | \$5.19   | ML BASE ADD NEXT? <u>.05</u> |
| 44.15    | \$5.24   | ML BASE ADD NEXT? <u>.05</u> |
| 44.20    | \$5.29   | ML BASE ADD NEXT? <u>.05</u> |
| 44.25    | \$5.34   | ML BASE ADD NEXT? <u>.05</u> |
| 44.30    | \$5.39   | ML BASE ADD NEXT? <u>.05</u> |
| 44.35    | \$5.44   | ML BASE ADD NEXT? <u>.05</u> |
| 44.40    | \$5.49   | ML BASE ADD NEXT? <u>.05</u> |
| 44.45    | \$5.54   | ML BASE ADD NEXT? <u>.05</u> |
| 44.50    | \$5.60   | ML BASE ADD NEXT? <u>.05</u> |
| 44.55    | \$5.65   | ML BASE ADD NEXT? <u>.05</u> |
| 44.60    | \$5.70   | ML BASE ADD NEXT? <u>.05</u> |
| 44.65    | \$5.75   | ML BASE ADD NEXT? <u>.05</u> |

THE INDICATOR HAS CHANGED COLOR. THE BASE IS NOW IN EXCESS.  
YOU HAVE ATTAINED ANALYTICAL PRECISION.

(44.70 ML NAOH SOLN)(1 LITER NAOH SOLN)(0.1255 MOLES NAOH)

-----  
(1000 ML NAOH SOLN)(LITER NAOH SOLN)

= .560985E-2 MOLES OF BASE ADDED

= .560985E-2 MOLES OF ACID ADDED

(.560985E-2 MOLES HCL)(1000 ML HCL SOLN)

-----  
(25.00 ML HCL SOLN) (1 LITER HCL SOLN)

= 0.2244 MOLAR ACID ORIGINALLY

DO YOU WANT ANOTHER SAMPLE OF THIS ACID (YES OR NO) ? YES

THIS IS TITRATION # 4 FOR THIS ACID.

| VOL.(ML) | TOT.COST |                                |
|----------|----------|--------------------------------|
| 0.00     | \$6.20   | ML BASE ADD NEXT? <u>44.63</u> |
| 44.63    | \$6.69   | ML BASE ADD NEXT? <u>.05</u>   |
| 44.68    | \$6.74   | ML BASE ADD NEXT? <u>.05</u>   |

THE INDICATOR HAS CHANGED COLOR. THE BASE IS NOW IN EXCESS.  
YOU HAVE ATTAINED ANALYTICAL PRECISION.

(44.73 ML NAOH SOLN)(1 LITER NAOH SOLN)(0.1255 MOLES NAOH)

-----  
(1000 ML NAOH SOLN)(LITER NAOH SOLN)

= .561361E-2 MOLES OF BASE ADDED

= .561361E-2 MOLES OF ACID ADDED

(.561361E-2 MOLES HCL)(1000 ML HCL SOLN)

-----  
(25.00 ML HCL SOLN) (1 LITER HCL SOLN)

= 0.2245 MOLAR ACID ORIGINALLY

DO YOU WANT ANOTHER SAMPLE OF THIS ACID (YES OR NO) ? NO  
DO YOU WANT TO TITRATE A DIFFERENT ACID (YES OR NO) ? NO

THEN YOU MUST THROW AWAY THE REMAINING 5.27 ML NAOH.  
UNDER NO CIRCUMSTANCES CAN THIS BE PUT BACK IN THE BOTTLE.  
THIS MAKES THE TOTAL COST OF YOUR LAST TITRATION \$6.85

CONGRADULATIONS. YOU ATTAINED ANALYTICAL ACCURACY  
ON EACH SAMPLE. REMEMBER YOUR STRATEGY WHEN YOU TITRATE IN LAB.

READY

## ENDPT Program Listing

READY

LIST

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ENDPT 09:29 24-JUN-75
10 REM ENDPT TITRATION SIMULATION GAME STRONG BASE-STRONG ACID
20 REM WRITTEN BY R.T.O'NEILL XAVIER UNIVERSITY,CINCINNATI 45207
30 REM THIS PROGRAM IS A PART OF THE SOLUTION STOICHIOMETRY UNIT
40 REM OF THE SOLUTIONS MODULE DEVELOPED AT THE IIT WORKSHOP,AUG.1974
60 REM*****COSTS
61 REM BASE COSTS $0.01/ML
62 REM A 25.00 ML UNKNOWN ACID COSTS $0.09
63 REM A DROP OF INDICATOR COSTS $0.01
64 REM PIPETING A 25.00 ML ACID SAMPLE (30 SEC) COSTS $0.10 IN LABOR
65 REM THE LABOR COST IN MAKING A BURET READING (15 SEC) IS $0.05
66 REM THE LABOR COST IN REFILLING A BURET (60 SEC) IS $0.20
67 REM TIME AND CHEMICAL COST FOR RINSING THE BURET THREE TIMES W. 10 ML
68 REM STANDARD BASE (30 SEC/RINSE) IS $0.60
70 REM RND AT LINES 310,320 SHOULD BE NON-REPEATING.
80 REM *****SUGGESTED MODIFICATIONS
81 REM RING BELL 5 TIMES AT LINE 655
82 REM HAVE'PRINT USING' **.* FOR V AND V2 AT L.500,817,915
83 REM HAVE'PRINT USING' *.*.* FOR M2 AND M3 AT L.355,818,860
84 REM HAVE'PRINT USING' **.* FOR C AT L. 500,930
90 LET X$="**.*" !DELETE FOR HP-3000
91 LET Y$="*.*.*" !DELETE FOR HP-3000
92 LET Z$="*.*.*.*" !DELETE FOR HP-3000
95 PRINT " ENDPT TITRATION SIMULATION GAME"
105 RANDOMIZE !DELETE THIS LINE FOR HP-3000
110 PRINT "DO YOU WISH INSTRUCTIONS (YES OR NO) ";
120 INPUT A$
130 IF A$="YES" THEN 7000
300 PRINT
310 LET M2=INT(300*RND(1)+1000)/10000
320 LET M1=INT(2200*RND(1)+400)/10000
325 IF M1/M2 > 2 THEN 310
330 LET N1=M1*.025
340 LET C=.6
350 LET T=0
355 PRINT"YOUR STANDARD BASE IS ";;PRINT USING Y$,M2;; PRINT" MOLAR."
356PRINT
360 PRINT "YOU HAVE JUST OBTAINED YOUR FIRST SAMPLE OF 25.00 ML OF AN"
370 PRINT "HCL SOLUTION OF UNKNOWN CONCENTRATION, AND FILLED UP YOUR"
380 PRINT "BURET WITH STANDARDIZED NAOH SOLUTION."
400 LET T=T+1
405 PRINT
410 PRINT "THIS IS TITRATION *";T;" FOR THIS ACID."
440 PRINT
450 LET V=0
460 LET C=C+.4
470 PRINT "VOL.(ML)";TAB(12);"TOT.COST"

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500PRINT USINGX$,V;:PRINT"      ";:PRINT USING Z$,C;:PRINT"      ML BASE A
DD NEXT";
520 INPUT A
530 IF A>=.05 THEN 570
531 IF A = 0 THEN 570
535 IF A>0 THEN 540
537 PRINT "NICE TRY, BUT YOU CAN'T SUBTRACT BASE ALREADY ADDED."
539 GOTO 500
540 PRINT "DON'T KID YOURSELF. YOU HAVEN'T PRACTICED TITRATION"
545 PRINT "ENOUGH YET TO BE ABLE TO SPLIT DROPS. A MINIMUM"
550 PRINT "OF .05 ML MUST BE ADDED."
560 GOTO 500
570 LET V=V+A
580 IF V<=50 THEN 630
590 PRINT "YOU HAVE DRAINED THE BURET BEYOND THE MARK WHERE YOU"
600 PRINT "CAN READ IT. THIS RUN IS RUINED."
610 LET C=C+.01*(50-V+A)
620 GOTO 400
630 LET C=C+.05+.01*A
646 IF N1>V*M2/1000 THEN 500
655 PRINT CHR$(7);CHR$(7);CHR$(7);CHR$(7);CHR$(7)
656PRINT"THE INDICATOR HAS CHANGED COLOR. THE BASE IS NOW IN EXCESS."
660 IF A=.05 THEN 800
670 PRINT "THE LAST VOLUME YOU ADDED WAS MORE THAN ONE DROP"
680 PRINT "(.05 ML) SO YOU'LL HAVE TO GET ANOTHER SAMPLE OF ACID."
690 GOTO 400
800 PRINT "YOU HAVE ATTAINED ANALYTICAL PRECISION."
810 LET V2=V
815 PRINT
817PRINT*(:;:PRINTUSING X$,V2;:PRINT" ML NAOH SOLN);:TAB(20);
818PRINT*(1 LITER NAOH SOLN)(;:PRINT USING Y$,M2;:PRINT" MOLES NAOH)"
819PRINT"-----"
820PRINT TAB(20);*(1000 ML NAOH SOLN)(LITER NAOH SOLN)"
821 PRINT
830 PRINT*=      ";M2*V*.001;" MOLES OF BASE ADDED"
839PRINT
840 PRINT*=      ";M2*V*.001;" MOLES OF ACID ADDED"
849PRINT
850PRINT*(:;M2*V*.001" MOLES HCL);:TAB(20);*(1000 ML HCL SOLN)"
851PRINT"-----"
852PRINT*(25.00 ML HCL SOLN);:TAB(24);*(1 LITER HCL SOLN)"
854PRINT
855 LET M3=M2*V*.04
860 PRINT*=      ";:PRINT USING Y$,M3;:PRINT" MOLAR ACID ORIGINALLY"
870 PRINT
880 PRINT
885PRINT"DO YOU WANT ANOTHER SAMPLE OF THIS ACID (YES OR NO) ";
890 INPUT A$
900 IF A$="YES" THEN 400
901 PRINT "DO YOU WANT TO TITRATE A DIFFERENT ACID (YES OR NO) ";
902 INPUT A$
903 IF A$ = "YES" THEN 300
905 LET V2=50-V
910PRINT

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915PRINT"THEN YOU MUST THROW AWAY THE REMAINING ";;PRINTUSINGX$,V2;;PRIN
T" ML NAOH."
920 PRINT "UNDER NO CIRCUMSTANCES CAN THIS BE PUT BACK IN THE BOTTLE."
925 LET C=C+V2*.01
926 LET V2=0
930PRINT"THIS MAKES THE TOTAL COST OF YOUR LAST TITRATION ";;PRINTUSINGZ
$,C
970 PRINT
980 PRINT "CONGRADULATIONS. YOU ATTAINED ANALYTICAL ACCURACY"
985 PRINT "ON EACH SAMPLE. REMEMBER YOUR STRATEGY WHEN YOU TITRATE IN LA
B."
990 PRINT
991 REM LINES 992-995 ARE FOR USE CHECK AND MAY BE OMITTED
992 OPEN"ENDPT.RECC231,10]"AS FILE 1 : INPUT#1 ,M
993 CLOSE#1
994 OPEN"ENDPT.RECC231,10]"AS FILE 1: PRINT #1, M+1
995 CLOSE #1
1000 GOTO 9999
7000 REM INSTRUCTIONS GO HERE
7010 PRINT "      YOU ARE GIVEN A LARGE SUPPLY OF STANDARD NAOH SOLUTION"
7020 PRINT "OF KNOWN MOLARITY, AND A 50-ML BURET TO DISPENSE IT WITH."
7030 PRINT"YOU CAN GET 25.00 ML SAMPLES OF HYDROCHLORIC"
7040 PRINT "ACID OF UNKNOWN MOLARITY. THE OBJECT OF THIS GAME IS TO"
7050 PRINT "EFFICIENTLY FIND THE MOLARITY OF THIS ACID BY TITRATING"
7060 PRINT "SAMPLES OF IT WITH THE BASE. AN INDICATOR ADDED TO THE"
7070 PRINT "SOLUTION WILL CHANGE COLOR WHEN YOU PASS THE EQUIVALENCE"
7080 PRINT "(END) POINT AND THE SOLUTION BECOMES BASIC. YOU M
UST"
7090 PRINT "ATTAIN ANALYTICAL PRECISION - - I.E. THE SOLUTION MUST"
7100 PRINT "CHANGE COLOR WHEN ONLY ONE DROP (.05 ML) IS ADDED."
7200 PRINT "      THE BEST STRATEGY IS **NOT** TO ADD SUCCESSIVE .05 ML"
7210 PRINT "PORTIONS IN THE FIRST TITRATION. ALTHOUGH CHEMICALS COST MON
EY (ABOUT"
7220 PRINT "1 CENT/ML FOR STANDARD BASE, 9 CENTS FOR A SAMPLE"
7230 PRINT "OF UNKNOWN ACID, 1 CENT FOR A DROP OF INDICATOR) YOUR TIME"
7240 PRINT "IS VALUABLE TOO. IF YOU ARE PAID $12/HR.,IT COSTS ABOUT"
7250 PRINT "5 CENTS TO TAKE A BURET READING,20 CENTS TO REFILL A BURET,"
7260 PRINT "AND 10 CENTS TO PIPETTE OUT A 25.00 ML SAMPLE OF ACID."
7270 PRINT "THE OBJECT OF THIS GAME IS TO ATTAIN ANALYTICAL RESULTS"
7280 PRINT "AT **MINIMUM COST**. WORK OUT YOUR OWN STRATEGY FOR DOING"
7290 PRINT "THIS BY TITRATING MORE THAN ONE SAMPLE."
7300 PRINT "      IT HAS ALREADY COST YOU $0.60 TO RINSE OUT THE"
7310 PRINT "BURET THREE TIMES WITH 10 ML PORTIONS OF THE BASE."
7315 REM OMIT NEXT LINE UNLESS YOU ARE USING 24 LINE CRT'S
7320 SLEEP 70
7900 GOTO 300
9999 END

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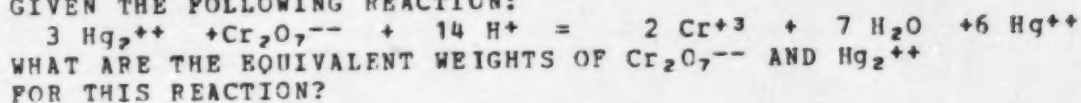
READY

Unit Test on Solution Stoichiometry time = 15 min.

TEST

1

1. GIVEN THE FOLLOWING REACTION:



2. WHAT VOLUME (IN ML) OF 0.943 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 91 ML OF 4.376E-01 M  $\text{NaHCO}_3$ ?
3. HOW MANY GRAMS OF  $\text{IO}_3^-$  IS NEEDED TO MAKE 503 ML OF A 0.156 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{IO}_3^-$  GOES TO  $\text{H}_5\text{IO}_6$ ?

Unit Test on Solution Stoichiometry time = 15 min.

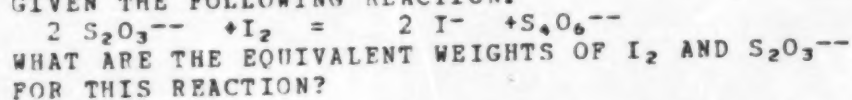
TEST

2

1. 10.9 ML OF A 0.767 NORMAL  $\text{Ag}^{++}$  SOLUTION IS REQUIRED TO TITRATE 35.3 ML OF A  $\text{IO}_3^-$  SOLUTION. HOW MANY GRAMS OF  $\text{IO}_3^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Ag}^+$  AND  $\text{H}_5\text{IO}_6$ .

2. WHAT VOLUME (IN ML) OF 0.925 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 6 ML OF 1.926E-01 M  $\text{HClO}_4$ ?

3. GIVEN THE FOLLOWING REACTION:



TEST 1

1. 30.67 200.60

2. 2.11E+01

3. 6.86E+00

TEST 2

1. 2.07E+01

2. 6.25E-01

3. 126.90 112.00

Unit Test on Solution Stoichiometry time = 15 min.

TEST

3

1. WHAT WEIGHT OF  $\text{Cu}^{++}$  IS NEEDED TO REACT WITH 0.325 G OF  $\text{H}_2\text{S}(\text{aq})$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Cu}^+$  AND S.
2. WHAT VOLUME(IN ML) OF 0.735 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 39 ML OF  $2.336\text{E}-01$  M  $\text{NaHCO}_3$ ?
3. 18.9 ML OF A 0.281 NORMAL  $\text{Tl}^{+3}$  SOLUTION IS REQUIRED TO TITRATE 18.8 ML OF A  $\text{Br}^-$  SOLUTION. HOW MANY GRAMS OF  $\text{Br}^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Tl}^+$  AND  $\text{Br}_2(\text{aq})$ .

Unit Test on Solution Stoichiometry time = 15 min.

TEST

4

1. 15.0 ML OF A 0.253 NORMAL  $\text{Br}_2(\text{aq})$  SOLUTION IS REQUIRED TO TITRATE 33.8 ML OF A  $\text{Fe}^{++}$  SOLUTION. HOW MANY GRAMS OF  $\text{Fe}^{++}$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Br}^-$  AND  $\text{Fe}^{+3}$ .
2. WHAT WEIGHT OF  $\text{Cr}_2\text{O}_7^{--}$  IS NEEDED TO REACT WITH 0.366 G OF  $\text{S}_2\text{O}_3^{--}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Cr}^{+3}$  AND  $\text{S}_4\text{O}_6^{--}$ .
3. WHAT VOLUME(IN ML) OF 0.938 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 116 ML OF  $6.262\text{E}-02$  M Benzoic acid?

TEST 3

1.  $1.21\text{E}+00$  G
2.  $6.20\text{E}+00$
3.  $2.26\text{E}+01$

TEST 4

1.  $6.27\text{E}+00$
2.  $1.00\text{E}-01$  G
3.  $3.87\text{E}+00$

Unit Test on Solution Stoichiometry time = 15 min.

TEST

5

1. 14.0 ML OF A 0.819 NORMAL  $\text{MnO}_4^-$  SOLUTION IS REQUIRED TO TITRATE 13.5 ML OF A  $\text{Tl}^+$  SOLUTION. HOW MANY GRAMS OF  $\text{Tl}^+$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Mn}^{++}$  AND  $\text{Tl}^{+3}$ .
2. GIVEN THE FOLLOWING REACTION:  

$$2 \text{I}^- + 2 \text{Co}^{+3} = 2 \text{Co}^{++} + \text{I}_2$$
 WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Co}^{+3}$  AND  $\text{I}^-$  FOR THIS REACTION?
3. WHAT VOLUME (IN ML) OF 0.419 M KOH WILL BE REQUIRED TO REACT COMPLETELY WITH 123 ML OF  $7.016\text{E}-01$  M  $\text{HNO}_3$ ?

Unit Test on Solution Stoichiometry time = 15 min.

TEST

6

1. HOW MANY GRAMS OF  $\text{H}_2\text{S}(\text{aq})$  IS NEEDED TO MAKE 463 ML OF A 0.183 NORMAL SOLUTION FOR A REACTION IN WHICH  $\text{H}_2\text{S}(\text{aq})$  GOES TO S?
2. WHAT WEIGHT OF  $\text{Ce}^{+4}$  IS NEEDED TO REACT WITH 0.335 G OF  $\text{Cu}^{+2}$ ? THE PRODUCTS OF THE REACTION ARE  $\text{Ce}^{+3}$  AND  $\text{Cu}^{++}$ .
3. WHAT VOLUME (IN ML) OF 0.129 M  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 138 ML OF  $3.566\text{E}-01$  M Formic acid?

TEST 5

TEST 6

1.  $8.68\text{E}+01$

1.  $1.44\text{E}+00$

2.  $7.39\text{E}-01$  G

2. 58.93 126.90

3.  $1.91\text{E}+02$

3.  $2.06\text{E}+02$

Unit Test on Solution Stoichiometry time = 15 min.

TEST

7

1. WHAT VOLUME (IN ML) OF 0.073 M  $\text{Ca}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 101 ML OF  $6.076\text{E}-01$  M Formic acid?
2. 16.5 ML OF A 0.220 NORMAL  $\text{MnO}_4^-$  SOLUTION IS REQUIRED TO TITRATE 32.7 ML OF A  $\text{Tl}^+$  SOLUTION. HOW MANY GRAMS OF  $\text{Tl}^+$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Mn}^{++}$  AND  $\text{Tl}^{+3}$ .
3. GIVEN THE FOLLOWING REACTION:  

$$3 \text{Sn}^{++} + 2 \text{NO}_3^- + 8 \text{H}^+ = 2 \text{NO} + 4 \text{H}_2\text{O} + 3 \text{Sn}^{+4}$$
 WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{NO}_3^-$  AND  $\text{Sn}^{++}$  FOR THIS REACTION?

Unit Test on Solution Stoichiometry time = 15 min.

TEST

8

1. 50.2 ML OF A 0.802 NORMAL  $\text{Co}^{+3}$  SOLUTION IS REQUIRED TO TITRATE 9.1 ML OF A  $\text{Br}^-$  SOLUTION. HOW MANY GRAMS OF  $\text{Br}^-$  PER LITER WAS IN THE SOLUTION? THE PRODUCTS OF THE REACTION WERE  $\text{Co}^{++}$  AND  $\text{Br}_2(\text{aq})$ .
2. WHAT VOLUME (IN ML) OF 0.946 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY WITH 113 ML OF  $9.316\text{E}-01$  M  $\text{HCN}$ ?
3. GIVEN THE FOLLOWING REACTION:  

$$6 \text{Fe}^{++} + \text{Cr}_2\text{O}_7^{--} + 14 \text{H}^+ = 2 \text{Cr}^{+3} + 7 \text{H}_2\text{O} + 6 \text{Fe}^{+3}$$
 WHAT ARE THE EQUIVALENT WEIGHTS OF  $\text{Cr}_2\text{O}_7^{--}$  AND  $\text{Fe}^{++}$  FOR THIS REACTION?

TEST 7

TEST 8

1.  $4.20\text{E}+02$

1.  $3.53\text{E}+02$

2.  $1.13\text{E}+01$

2.  $5.56\text{E}+01$

3. 20.67 59.35

3. 30.67 55.85

Unit Test on Solution Stoichiometry time = 15 min.

TEST

9

1. WHAT WEIGHT OF  $\text{Ce}^{++}$  IS NEEDED TO REACT WITH 0.933 G OF  $\text{Cr}^{+3}$ ?  
THE PRODUCTS OF THE REACTION ARE  $\text{Ce}^{+3}$  AND  $\text{Cr}_2\text{O}_7^{--}$ .
2. HOW MANY GRAMS OF  $\text{I}^-$  IS NEEDED TO MAKE  
490 ML OF A 0.132 NORMAL SOLUTION FOR A REACTION  
IN WHICH  $\text{I}^-$  GOES TO  $\text{I}_2$  ?
3. WHAT VOLUME (IN ML) OF 0.373 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY  
WITH 137 ML OF  $1.796\text{E-}01$  M  $\text{HCN}$ ?

Unit Test on Solution Stoichiometry time = 15 min.

TEST

10

1. WHAT VOLUME (IN ML) OF 0.686 M  $\text{Ba}(\text{OH})_2$  WILL BE REQUIRED TO REACT COMPLETELY  
WITH 78 ML OF  $9.366\text{E-}01$  M  $\text{HCN}$ ?
2. WHAT WEIGHT OF  $\text{H}_5\text{IO}_6$  IS NEEDED TO REACT WITH 0.852 G OF  $\text{Hg}_2^{++}$ ?  
THE PRODUCTS OF THE REACTION ARE  $\text{IO}_3^-$  AND  $\text{Hg}^{++}$ .
3. HOW MANY GRAMS OF  $\text{Hg}_2^{++}$  IS NEEDED TO MAKE  
436 ML OF A 0.482 NORMAL SOLUTION FOR A REACTION  
IN WHICH  $\text{Hg}_2^{++}$  GOES TO  $\text{Hg}^{++}$  ?

TEST 9

1.  $7.54\text{E+}00$  G
2.  $8.21\text{E+}00$
3.  $3.30\text{E+}01$

TEST 10

1.  $5.32\text{E+}01$
2.  $4.84\text{E-}01$  G
3.  $4.22\text{E+}01$